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SPECIAL SECTION / SECTION THÉMATIQUE

GMOs and poverty: the relationship between improved seeds and rural transformations

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ABSTRACT
This essay draws on the extensive empirical literature to address the question: Can genetically modified (GM) crops help poor people? The evidence suggests that GM crops can generate sizeable yield advantages for small-scale farming families in low-income countries through avoiding losses to pests and disease. These advantages may improve considerably the welfare of people who depend on farming for most of their income. However, since poverty is a complex phenomenon and improved seed in and of itself plays a limited role in rural transformation, much more is needed to generate an impact on poverty, including investments in the architecture of rural institutions and farmer knowledge.

RÉSUMÉ
D'après les données probantes issues de nombreuses études empiriques, les cultures génétiquement modifiées (GM) peuvent, en prévenant les pertes dues aux parasites et aux maladies, générer des bénéfices substantiels pour les familles des petits exploitants agricoles des pays à faible revenu. Elles sont susceptibles d'améliorer de façon considérable le bien-être des populations dont la majeure partie des revenus provient de l'agriculture. Cependant, parce que la pauvreté est un phénomène complexe et que les semences améliorées jouent en elles-mêmes un rôle limité dans la transformation du milieu rural, d'autres conditions comme des investissements dans l'architecture des institutions rurales et dans la formation des agriculteurs sont essentielles pour générer un effet sur la pauvreté.

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When we ask whether genetically modified (GM) crops have the potential to reduce poverty among smallholder farmers in the developing world, it is useful to recall what we have already learned about the relationship between rural poverty and seed innovations in low-income countries. An abundant, empirical literature examines the social and economic effects of seed-based technical change during the process of agricultural development, and also the determinants of rural poverty. However, demonstrating a causal relationship between adoption of seed innovations and poverty reduction is surprisingly complex: the causes of rural poverty are manifold, the range of intervening factors is large at any point in time and the time period covered by the analysis matters. The

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literature documenting the impacts of GM crops on farmers is substantial and growing, but comprehensive analyses relating adoption of GM crops to poverty reduction are few.

In a thumbnail sketch of empirical research on poverty and seed innovations, I rely heavily on several key reviews: a global analysis of the state of family farms, conducted by the Food and Agriculture Organization of the United Nations (FAO 2014); a summary of longitudinal research on the causes of chronic poverty (Baulch 2011); and Hazell's (2010) most recent review of Green Revolution. Turning to GM crops, I then draw from summaries and meta-analyses conducted by Smale et al. (2009), Finger et al. (2011), Areal, Riesgo, and Rodríguez-Cerezo (2013), Klümper and Qaim (2014) and Fischer et al. (2015). I also offer some highlights from a collection of case studies led by Smale and Falck-Zepeda (2012), conducted on modest research budgets in low-income countries, and a related set of studies focusing on Bt cotton (Tripp 2009).[1]

My arguments are basic. First, since the world's family farmers are diverse and their contexts are heterogeneous, no single developmental approach, let alone a seed type, will be universally successful in raising their income. Second, given that the roots of poverty are complex and farm family incomes in developing countries are composed of multiple sources, reducing poverty requires more than a few successful harvests. Third, the most well-known model we have, a seed-based technical change (the Green Revolution), demonstrates the importance of other inputs, institutions and policies in achieving change, and also that poverty persists. Broad-based investments in farmer knowledge systems, institutional development and policy reforms are thus fundamental if GM seed is to have an impact on rural poverty.

Who produces the world's food?

Despite the industrialisation of agriculture worldwide over the past century, family farming is still the predominant social and economic unit of agricultural production. According to *The State of Food and Agriculture 2014* (SOFA), over 500 million family farms manage the majority of the world's farmland and also produce most of its food (FAO 2014). Although family farms may be commercially-oriented, meaning that families may carefully consider the costs and benefits of their crop and livestock enterprises, family farms differ in fundamental ways from commercial farming operations. First, the vast majority of these farms are small or very small, and probably becoming smaller. For example, the SOFA reports that 94 per cent of all farms measure less than five hectares in size (72% are less than one hectare). The burden of the evidence does suggest that, in part because families manage their land and labour very intensively, farm productivity (output per hectare, or yield) tends to be high on smaller- compared with larger-scale operations.

Farm families in low-income countries do not tend to run their farms in the same way as industrial farms or fully-commercialised, for-profit enterprises that are well integrated into market value chains and/or export markets. An old adage in North America was that farm families "tighten their belts" in times of duress; generally, returns per hour of labour may be low in family farming. Each farm family faces its own "shadow prices" depending upon its labour and capital endowments, and in rural communities around the world, economic calculus is often shaped by social norms.

But most importantly in terms of development policy, the fact that family farmers are a heterogeneous group (even within a country) means that they are hard to reach with cookie-cutter, "one-size fits all" policies designed to enhance their productivity and welfare. A corollary is that the capacity to formulate and implement location-specific policies is crucial for promoting farming innovations. Some family farmers operate relatively large-scale areas and require little other than access to advanced information and the latest research (group 1); other family farms operate smaller areas in intensive systems close to urban markets, seeking to reduce marketing margins and obtain the latest sales information (group 2); still others farm in remote areas and engage in markets primarily as net food buyers (group 3); another group are virtually landless (group 4). For the first two groups, if soft and hard infrastructure (both services, such as credit, and physical structures, such as roads) are "right", the latest seed technology may prove profitable. For the third group, small changes in productivity can mean a significant seasonal difference in caloric intake. Farming innovations may do little to solve the problems of the fourth group. Investment in local non-farm opportunities may serve them better.

While these conditions may seem simple, there are many reasons why they are not. Farm policies are politically motivated and subject to the control of interest groups. Politically powerful, farm interest groups generally do not include dispersed, small-scale farm families but well-organised producers of crops that are important to the national economy. Meanwhile, the effectiveness of policies depends on strong agricultural information services, which are costly to establish and maintain. As a public good, agricultural information is most often funded by the public sector, and governments in most developing countries have severely constrained budgets.

Moreover, not only are family farms heterogeneous but also a change in profitability, or a change in caloric intake in any one cropping season, is not likely to mean that a farm family leaves poverty behind.

What causes poverty?

From 2000 to 2010, researchers at the Chronic Poverty Research Centre and the International Food Policy Research Institute studied the processes by which poor people move into and out of poverty in low-income countries (Baulch and Hoddinott 2000; Baulch 2011). In the initial set of studies, in which they provided a conceptual framework that served as the basis for empirical analysis in the subsequent decade, they found that some poor people remained poor over time, while others (and by far the largest group) tended to move into and out of poverty.

The second set of longitudinal studies represented four countries in Asia (Bangladesh, Nepal, Pakistan, Vietnam) and two in Africa (Ethiopia, South Africa). Researchers concluded that illiteracy or lack of education, lack of assets and marginalisation due to ethnicity, caste or race tend to lock people into persistent poverty. Adverse geography (living in remote, unproductive regions) and social obligations also play important roles in perpetuating poverty. Widowhood or loss of male relatives is a major risk factor among women. But rather than a single shock, it is usually several in sequence that push households into chronic poverty.

Researchers found limited evidence of a "threshold" in asset ownership beyond which households were more likely to escape from chronic poverty. Processes leading to escape from poverty are not smooth as is depicted in economic theory; asset accumulation, which ensures future income, is interrupted by shocks and negative events (the death of a family member, natural disasters, violence). Households able to leave poverty are often at an earlier stage of the life cycle, during which children are small and both parents work. Later, the burdens of childcare, education and elderly parents strain family resources, often resulting in a lapse into poverty.

Regular employment was found to be a major factor enabling exit from poverty, and often the most regular salary is that generated by non-farm employment, rather than farming. Generally, because non-farm earnings are uncorrelated with farm earnings, they serve to offset income shocks from bad harvests. In sub-Saharan Africa, income from non-farm sources now represents a substantial portion of the total household income of farm families. More than a decade ago, Bryceson (2000) reported case study findings of non-farm earnings that ranged from 55 per cent to 80 per cent of household income. Considering farm surveys conducted in 23 countries during the 1990s and 2000s, Reardon, Stamoulis, and Pingali (2007) reported that non-farm income represented an average of 34 per cent of rural household income. Nationally representative survey data collected in Kenya last year suggest an average non-farm income share of nearly 56 per cent among rural households (Tegemeo Institute, personal communication, 10 July 2015). This suggests that for some poor rural households, non-farm work may serve as a more effective pathway out of poverty, although conclusive evidence to this point is not yet available.

Given the complexity of poverty and the importance of non-farm income in household income, how large a role might seed innovations play in reducing it?

What role does improved seed play in reducing poverty?

For those who have studied agricultural development over the past half-century, the most well-known model about the effects of seed innovations on poverty is the Green Revolution (for a recent review, see Hazell 2010; with reference to Latin American, see Otero 2012). Technically, the Green Revolution refers to the rapid spread of short-strawed, fertiliser-responsive varieties of wheat and rice in the 1960s–1970s in Asia. Initially, these were adopted in the irrigated areas in which moisture conditions enabled the strongest yield gains. Later, they diffused more slowly in rain-fed areas in which yield gains were more variable. Seed-based technical change led to sharp increases in agricultural growth in many Asian countries, generating demand for rural labour, leading to higher rural wages, and a greater supply of food at lower prices that could be purchased by labourers and food-deficient households.

That said, at least three aspects of the Green Revolution model limit its applicability to our question. First, technical change resulted not only from adopting improved seed but also from greater use of fertiliser, pesticides and recommended agronomic practices. Second, productivity growth was predicated on major public investments by governments in irrigation, roads and marketing systems, as well as land reform and subsidies. As expressed by Hazell (2010, 69), “attempts have been made to separate the contributions of the different components of the Green Revolution package, but in practice it is the combined impact of interventions and their power interactions that made the difference”.

Third, despite the massive rural changes that ensued, large numbers of people remained in poverty across Asia after the Green Revolution. As stated aptly by Lipton and Longhurst ([1989] 2011, 3):

> There have been massive rises in the yields of staple food crops eaten, grown and worked mainly by poor people. There have been positive effects on employment, and on the availability, cheapness and security of food. Yet there have been delayed, scanty, sometimes faltering and imperceptible improvements in the lot of the poor.

Meanwhile, empirical evidence of such transformations in sub-Saharan Africa remains limited (Otsuka and Larson 2013).

What is the evidence about GM crops and poverty?

The geographical distribution of the area planted to GM crops, by income level of the country (according to the World Bank), is shown in Figure A1 (see Appendix). Six countries account for 92 per cent of the area planted to GM crops. Listed in order of magnitude, these are: the USA, Brazil, Argentina, India, Canada and China. None of these are low-income countries. Brazil, Argentina and China are upper-middle-income countries, and India is a lower-middle-income country. The USA and Canada are, of course, high income. Out of all 27 adopting countries, only two are low-income: Myanmar and Burkina Faso. Each of these accounted for less than 0.3 per cent of the total global area planted to GM crops in 2014. Thus, there are lead country adopters, and these are not the lower-income nations of the world.

Empirical evidence generally shows that within countries, as with any agricultural innovation, adopters are often lead farmers. Early adopters tend to be among the better-off farmers in communities. Poorer farmers have less access to various forms of capital, including physical capital (land resources, equipment), financial capital (cash and credit) and human capital (education, literacy, experience). Capital constraints mean that transaction costs of obtaining information that accompanies new technology can pose barriers to adoption. Even more importantly, high rates of adoption may occur if seed is supplied directly to farmers along with credit and an assured market for the crop, but if farmers have limited capital, they may not have access to the information that enables them to manage the crop well or the means to continue growing it once the vertically-integrated supply channel has been removed. Such a case has been described for Makhathini Flats in South Africa, which was originally hailed as a success story (Gouse et al. 2005).

In 2016, nearly 20 years after their initial release, only four crops account for 98 per cent of the area (soybean, cotton, maize and canola). Of these, GM cotton is the most extensively grown by smallholder farmers. Following their initial release in the USA in 1996, experts predicted that Bt cotton varieties would boost yields, especially in developing agricultural economies, where conventional methods of controlling these pests – which involve the repeated application of insecticides – are especially costly or poorly managed (for example, Qaim and Zilberman 2003). Subsequent reviews of economic analyses based on farm surveys (Qaim 2009; Smale et al. 2009), as well as meta-analyses (Finger et al. 2011; Areal, Riesgo, and Rodríguez-Cerezo 2013; Klümper and Qaim 2014; Fischer et al. 2015), have generally borne out this prediction.

Early published studies about the economic impact of biotech crops on farmers in developing countries shared several methodological limitations (Smale et al. 2009). Many of these, such as selection bias, endogeneity problems and redundant analyses based on the same relatively small datasets, have since been addressed by researchers, although the number of traits studied, and the number of independent, ex-post farm studies, remains few. Most studies were, and continue to be, about Bt cotton. In the first decade of its use, while overall evidence was positive for yield and farm income, there was great variability across sites and genetic materials.

The recent article by Klümper and Qaim (2014) addresses many of the methodological challenges that characterised the first generation of studies about the economic impacts of GM crops on smallholder farmers in low-income countries. For example, the authors controlled for whether the study was conducted by the industry and whether it was based on the same dataset as an earlier analysis. They present robust positive evidence of economic impacts, with larger estimated benefits in developing than developed countries, and more for insect resistance than herbicide tolerance. Echoing the point raised at the beginning of this section, one limitation of the study is that the developing country category used by Klümper and Qaim (2014) includes such disparate members as Argentina and Burkina Faso.

In researching GM crops, compared to other improved seed, methodological difficulties are often exacerbated by political sensitivities. Biotech crops have features that make it more difficult to assess costs and benefits with accuracy. Some of these are explored in a collection of applied economics studies (Smale and Falck-Zepeda 2012) conducted in countries in which GM crops had recently been introduced and little research had been implemented to measure their impacts on farm families. The research team designed the field studies with the objective of pilot testing "good practices" with the modest research budgets expected by most developing country scientists. At the time of the Bolivia case study, the Bolivian National Constitution prohibited the commercialisation of GM crops, but the decree permitting the unique event of glyphosate tolerance was enacted earlier and herbicide-tolerant (HT) soybean was diffused by farmers. Political sensitivities affected willingness of communities and farmers to be interviewed. In the Honduras case, company control biased the lists provided publicly for sampling farmers.

Farmers in low-income countries have heard less and know less about biotech crops. Attitudes and preferences are time- and information-dependent. Early adopters know less because they are "discovering" GM crops, and farmers who know less face greater risk and uncertainty. Gender has also been an understudied aspect of GM adoption. Zambrano et al. (2012) found that, contrary to popular belief in Colombia, women participate in several Bt cotton crop operations, some of which were not visible until they were interviewed separately. The authors also observed that the problem of lack of information, and timeliness of information, was more acute for women than for men.

Finally, most of the existing body of research, including the analysis by Klümper and Qaim (2014), has focused on establishing the impacts of GM adoption on pesticide use, costs, abating losses to pests and profits, but not poverty per se. As noted above, analysing poverty impacts requires longitudinal analysis and strong methodologies to disentangle cause and effect. As of 1 December 2015, we identified only 14 peer-reviewed journal articles (Table 1) that address poverty and GM crops with a stated methodology, of

Table 1. List of peer-reviewed articles explicitly addressing the impacts of GM crops on poverty, including a stated methodology (as of 1 December 2015).

1. Ali, A., and A. Abdulai. 2010. "The Adoption of Genetically Modified Cotton and Poverty Reduction in Pakistan." *Journal of Agricultural Economics* 61(1): 175–192.
2. Francisco, S.R., C.A. Aragon, and G.W. Norton. 2012. "Potential Poverty Reducing Impacts of Bt Eggplant Adoption in the Philippines." *Philippine Journal of Crop Science* 37: 30–39.
3. Graff, G., D. Roland-Holst, and D. Zilberman. 2006. "Agricultural Biotechnology and Poverty Reduction in Low-Income Countries." *World Development* 34(8): 1430–1445.
4. Glover, D. 2010. Is Bt Cotton a Pro-Poor Technology? A Review and Critique of the Empirical Record." *Journal of Agrarian Change* 10(4): 482–509, doi:10.1111/j.1471-0366.2010.00283.x.
5. Ivanic, M., and W. Martin. 2010. "Poverty Impacts of Improved Agricultural Productivity: Opportunities for Genetically Modified Crops." *AgBioForum – Journal of Agrobiotechnology Management & Economics* 13(4): 308–313.
6. Piesse, J. and C. Thirtle. 2008. "Genetically Modified Crops, Factor Endowments, Biased Technological Change, Wages and Poverty Reduction." *International Journal of Biotecholology* 10 (2–3), 184–206, doi:10.1504/ijbt.2008.018354.
7. Pray, C.E. and A. Naseem. 2007. "Supplying Crop Biotechnology to the Poor: Opportunities and Constraints." *Journal of Development Studies* 43(1), 192–217, doi:10.1080/00220380601055676.
8. Qaim, M. 2010. "Benefits of Genetically Modified Crops for the Poor: Household Income, Nutrition, and Health." *New Biotechnology* 27(5), 552–557, doi:10.1016/j.nbt.2010.07.009.
9. Qaim, M., and S. Kouser. 2013. "Genetically Modified Crops and Food Security. *PLoS ONE* 8(6): e64879. doi:10.1371/journal.pone.0064879.
10. Rao, N.C. and S.M. Dev. 2009. "Biotechnology and Pro-Poor Agricultural Development." *Economic and Political Weekly*. 44: 56–64.
11. Fukuda-Parr. S. 2012. "The Gene Revolution: GM Crops and Unequal Development." London: Earthscan.
12. Subramanian, A and M. Qaim. 2010. "The Impact of Bt Cotton on Poor Households in Rural India." *Journal of Development Studies* 46(2): 295–311.
13. Torres, C.S., R.A. Daya, T.B. Osalla, and J.N. Gopela. 2013. "Adoption and Uptake Pathways of GM/Biotech Crops by Small-Scale, Resource-Poor Farmers in the Philippines." Laguna, Philippines: International Service for the Acquisition of Agri-biotech Applications (ISAAA). Available at: https://www.isaaa.org/programs/specialprojects/templeton/adoption/philippines/Philippines-Adoption%20and%20Uptake%20Pathways.pdf (accessed 18 July 2016).

Source: bEcon (http://ebrary.ifpri.org/cdm/search/collection/p15738coll6); Finger et al. (2011); Areal, Riesgo, and Rodríguez-Cerezo (2013); Klümper and Qaim (2014); Fischer et al. (2015).

which we consider the most pertinent and rigorous to be the study by Subramanian and Qaim (2010).

Conclusions

There is little doubt that GM crops can generate sizeable yield advantages for small-scale farm families through avoiding damage from pests and disease, and that these yield advantages can have a major effect on welfare of poor farmers who rely on the crop for their livelihoods. For GM crops to reduce poverty, however, more is needed. In general, reducing rural poverty requires broad-based investments in which not only seed technologies and market-based institutions but also education and equitable access to resources such as land play a role.

For seed-based technical change to succeed, it must be accompanied by strong rural institutions that enable farmers to understand the crop they are adopting, learn from growing it and be able to rely on input and output markets from one year to the next. Seed is a minor contributor in the quest for poverty reduction, although it can, and has, served as a catalyst. Investments in rural development should therefore accompany investments in biotechnology.

Given the heterogeneity of family farmers in the developing world, a "one-size fits all" solution is not likely to have a measurable impact on adoption or poverty reduction. For any promising agricultural technology, widespread adoption will not depend on cutting edge science alone but also on innovative, decentralised or locally-based models for extending technology and information. Investments are needed in novel agricultural information systems that are accessible to dispersed farmers, in farmer education, knowledge formation, and civil society. As Tripp (2009) concluded, the institutional architecture that determines how a new agricultural technology is utilised is of pre-eminent importance; if this is not addressed, there is little potential for GM crops to be widely used, let alone to reduce poverty.

Note

1. The case studies led and summarised by Smale and Falck-Zepeda (2012) were funded by Canada's International Development Research Centre (IDRC), and as part of the same project, Oxfam America funded the studies led and synthesised by Tripp (2009).

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Notes on contributor

Melinda Smale joined Michigan State University in 2011 as Professor for International Development, after working for over 25 years in research conducted with developing country scientists at the International Food Policy Research Institute, the International Maize and Wheat Improvement Center and Bioversity International. She has led projects on the adoption of agricultural innovations, economic impacts of biotech crops and agricultural biodiversity, and has published over 80 articles in peer-reviewed journals and five edited books.

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Hazell, P. B. R. 2010. "The Asian Green Revolution." In *Proven Successes in Agricultural Development: A Technical Compendium to Millions Fed*, edited by D. Spielman and R. Pandya-Lorch, 67–98. Washington, DC: International Food Policy Research Institute.

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Appendix

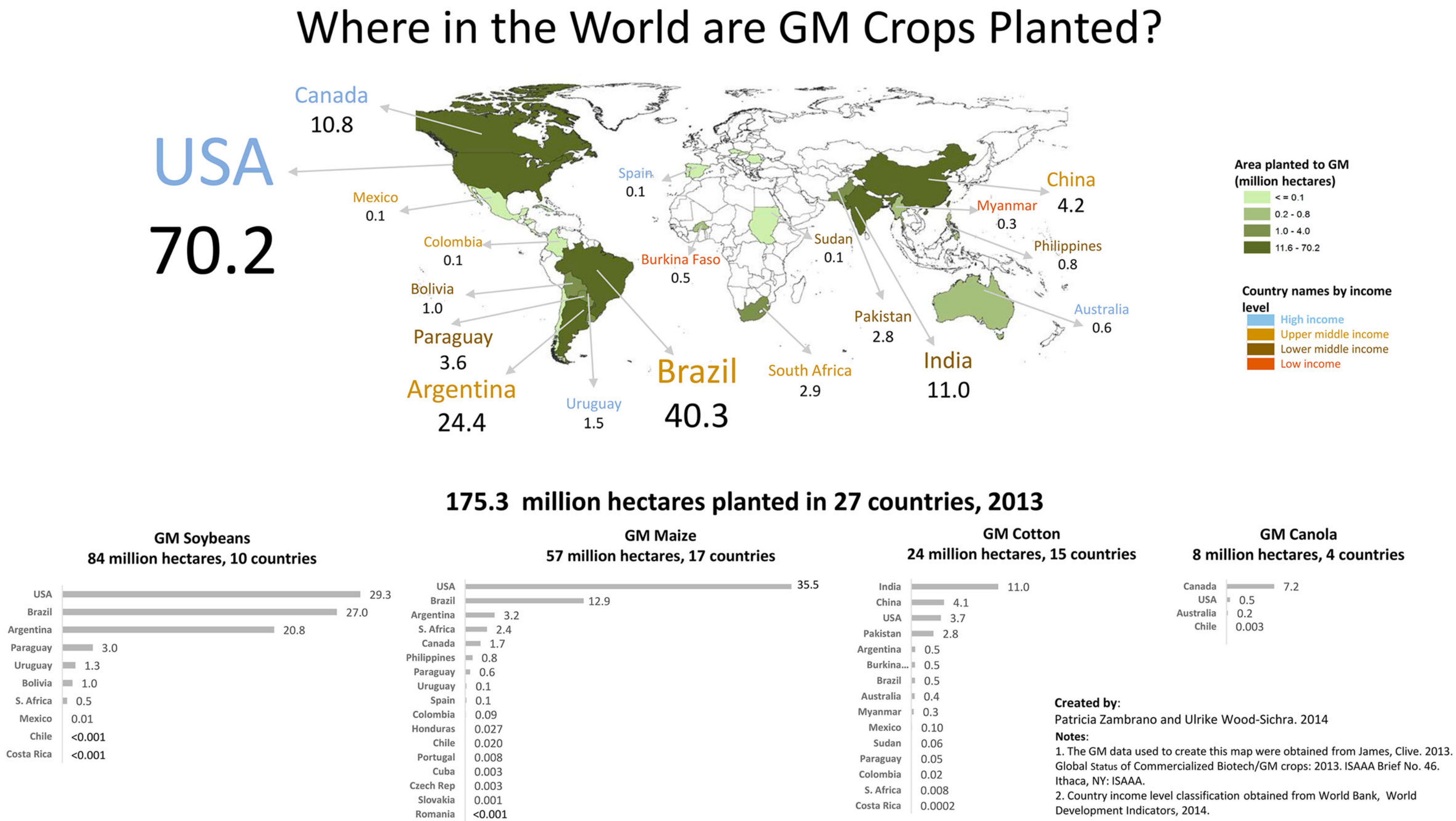

Figure A1. Map showing geographical location of GM crops, by income level of country. Source: IFPRI 2014 (accessed 16 June 2016).